

## EFFICIENCY AND QUALITY

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### RATIONAL APPROACHES TO REGULATING THE REDOX PROPERTIES OF BATCH FOR FLOAT-GLASS PRODUCTION

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Optimization of the physical-chemical processes occurring during the preparation of glass batch, improvement of the batch preparation processes, transport, and feeding into the glassmaking furnace, and the quality indicators of batch are all important but not decisive to obtaining high-quality finished product — glass. Together with these factors the redox properties of the components used for preparing batch and the batch itself as well as the redox potential of molten glass made from the batch are of enormous importance for the glassmaking process and for the quality of molten glass. This article analyzes the redox processes occurring during melting of the sulfate of soda batch with float-glass composition and the optimization of sodium sulfate and carbon addition to the batch in order to obtain a batch that increases the stability of the melting process and the output and improves the quality of the final product with respect to defects such as bubbles and inclusions.

**Key words:** glass batch, redox reaction, redox potential, carbon, sodium sulfate, optimization.

Optimization of the physical-chemical processes during the preparation of glass batch is important for obtaining a high-quality batch. The following factors must be taken into account [1]:

- particle-size distribution in the batch after the raw materials have been mixed;
- batch temperature after the raw materials have been mixed;
- moisture content of the batch;
- method of feeding and mixing cullet and constancy of the batch/cullet ratio.

However, attaining optimal batch-quality parameters in the dispensing-mixing shop is found to be inadequate.

Studies of the technological process have established that the batch quality indicators at the time the batch is loaded into the glass furnace are important for the efficiency of the glassmaking process. For this reason, a new method of loading batch into a glass furnace was proposed [2].

Improvement of the processes involved in the preparation, transport, and feeding of batch into a glass furnace had a positive effect on glass making and the quality of the final product.

However, in analyzing the operation of two float-lines (the observations were performed over a period of one month) it was noticed that for the same technological parameters of the operation of glass furnaces, such as the capacity and batch/cullet ratio, and for the same batch composition, fluctuations of the bottom temperatures in the melting zone and of the gas temperature, including in the maximum temperature zone, arose periodically (repeatedly) and simultaneously in both lines. Such changes often increased the number of gas inclusions in the form of stony inclusions and striae, which undoubtedly lowered the quality of the glass and the molten-glass utilization factor (MUF).

This required a deeper analysis of the redox properties of the components used for preparing batch and the mixture and redox potential of the molten glass made using this mixture. This is especially important because active oxidizing and reducing agents (sodium sulfate and carbon) are used in the batch and one of the aims of the present work is to optimize their amounts.

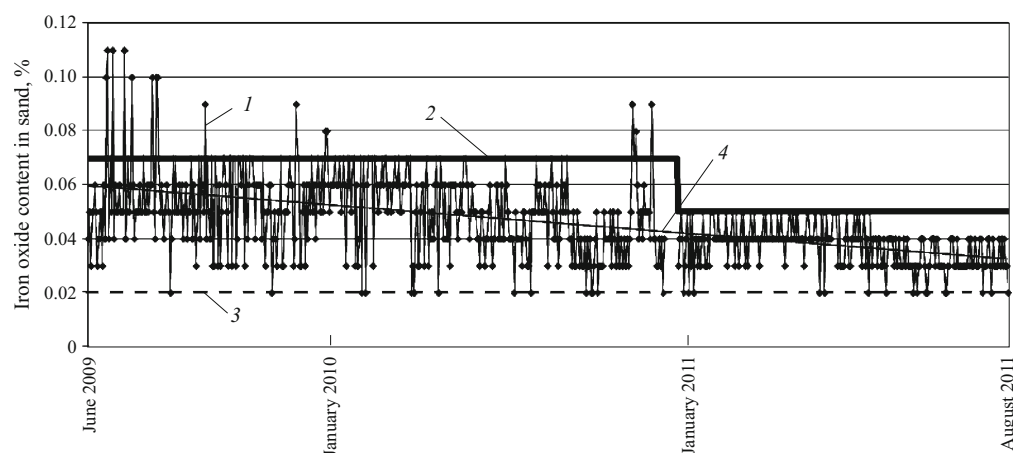
It is known that the redox potential (ORP) of the raw material and batch must be systematically monitored in order to create the redox conditions required for glassmaking, which, in turn, affects the glassmaking and molding process itself [3].

One objective of the present work is to analyze the redox processes occurring during fusion of a sulfate of soda mix-

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**Fig. 1.** Iron oxide  $\text{Fe}_2\text{O}_3$  content in sand (according to the results of intake checking): 1) actual (measurements); 2, 3) established maximum and minimum values, respectively; 4) average value.

ture for producing float-glass as well as to optimize the introduction of sodium sulfate and carbon in the mixture in order to obtain a batch that further improves the stability of the glassmaking process, increases output, and improves product quality with respect to defects in the form of bubbles and inclusions.

The initial materials used in the manufacture of sheet glass always contain iron oxides, which are elements with a variable degree of oxidation, in the form of impurities.

In addition, iron is present in glass not only as an impurity in the initial materials but also because equipment iron enters the furnace together with the batch and cullet.

Iron mainly in the form  $\text{Fe}^{2+}$  ( $\text{FeO}$ ) affects the glassmaking and molding processes.  $\text{FeO}$  lowers the total light transmission of the glass and the diathermancy of the molten glass in the furnace to a greater extent than  $\text{Fe}^{3+}$  ( $\text{Fe}_2\text{O}_3$ ). The change of the light transmission of the glass and the disruption of the stability of the technological process are due to the change in the total iron content and especially the ratio of  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$ .

A shift of the process in the direction of  $\text{Fe}^{3+}$  production causes the bottom layers of the molten glass to fuse, which is the main reason for the appearance of bubbles, stony inclusion, and striae in the glass and lowers (fuel consumption remaining constant) the temperature of the gas space of the furnace in the melting zone.

Methods of shifting the equilibrium  $\text{Fe}^{2+} \rightleftharpoons \text{Fe}^{3+}$  rightward form the basis of chemical decolorization of glass.

Sporadic disruptions of the stability of the glassmaking process, which are caused primarily by a change of the diathermancy of the melt, made it necessary to lower the content of iron oxides in the glass and evaluate the redox properties of the initial materials, batch, and glass.

In 2011 measures to acquire quartz sand with iron oxide content  $0.03 - 0.04\%$ <sup>4</sup> and lower in terms of  $\text{Fe}_2\text{O}_3$  were taken in order to lower the content of iron oxides in glass and to increase the light transmission of glass. In April 2011 a transition was initiated from sand with iron oxide content  $0.05 - 0.07\%$  to sand with iron oxide content  $0.04\%$  and

lower in the feeding hoppers. These measures, which required changing suppliers of quartz sand and increasing sand quality, taken together made it possible to lower the iron oxides content in sand considerably (Fig. 1).

In addition, to lower the iron content in glass a scheme for treating the initial materials was instituted and more efficient magnetic separators were installed in the lines feeding the batch and cullet. This made it possible not only to completely prevent metallic impurities from entering the tank furnace but also to lower by a factor of 1.5 – 2.0 the amount of equipment iron entering the batch. As a result, the iron oxide content in the glass was lowered from 0.089 to 0.078% (Fig. 2).

At the second stage, magnetic separators for all forms of the initial materials will be installed in front of the batch mixers.

Glass is made using sand, both enriched and non-enriched, from different suppliers. In this connection, sand with the following properties was analyzed and selected:

- particle-size distribution —  $0.3 - 0.1$  mm grain content to 80%;
- iron oxide content  $0.03 - 0.04\%$ ;
- chemical requirement for oxygen (CRO) — 37 – 42 mg oxygen/100 kg sand.

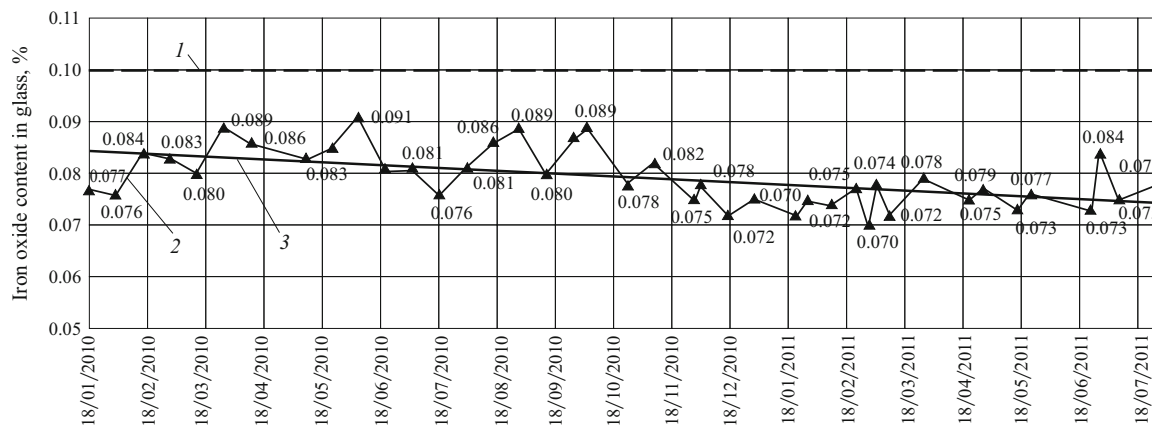
A number of initial materials, especially feldspar, chalk, and dolomite, have an elevated iron content ranging from 0.14 to 0.41%. Over the period from July to August 2011 the CRO was analyzed for all initial materials, i.e., the amount of oxygen for oxidizing the reducing agents and impurities in the initial materials and batch was determined. It was found that the CRO of the initial materials fluctuates considerably. The chemical requirement for oxygen in the batch also fluctuated sharply in July and at the beginning of August. These changes were stabilized in the second half of August and at the beginning of September (Fig. 3).

Figure 4 displays the RedOx value, defined as the ratio

$$\text{RedOx} = \frac{\text{FeO}}{\text{Fe}_2\text{O}_3 + \text{FeO}},$$

for glass over the observation period starting in April 2011.

<sup>4</sup> Here and below, content by weight.



**Fig. 2.** Total iron oxide content (in terms of  $\text{Fe}_2\text{O}_3$ ) in the float-line glass in plant No. 3: 1) proven maximum value; 2) actual value; 3) average value.

In addition, systematic monitoring of the redox potential of the initial materials and batch on the basis of the analytical determinations of their requirements for oxygen (CRO) was implemented.

The initial materials used for preparing glass mixture vary from one raw materials batch to another. Because of the nonuniformity and contamination of the materials found in nature the CRO of the materials (supplied to the same producers, according to the same normative-technical documentation) varies under real conditions over wide limits: sand — 70 – 230; feldspar — 60 – 85; chalk — 35 – 70; sodium sulfate: naturally occurring — 20 – 35, synthetic — 100 – 580; cullet — 100 – 120 [3].

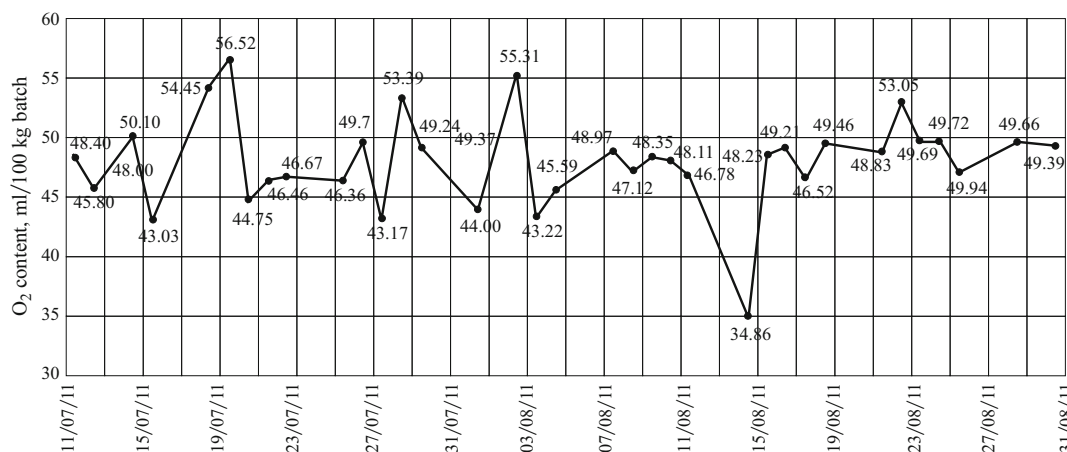
The dependence of the redox properties of the batch and molten glass obtained using it on the content of  $\text{FeO}$  and  $\text{Fe}_2\text{O}_3$  and their ratio is obvious. Changes, especially with sharp fluctuations of the content of iron oxides in the glass, are accompanied by considerable fluctuations of the molten-glass temperature (bottom, beneath the batch) and of the maximum temperature of the gas space. As a result, bubbles

and inclusions of silica products of crystallization and so forth increase in size, degrading the quality of the finished product (Fig. 5).

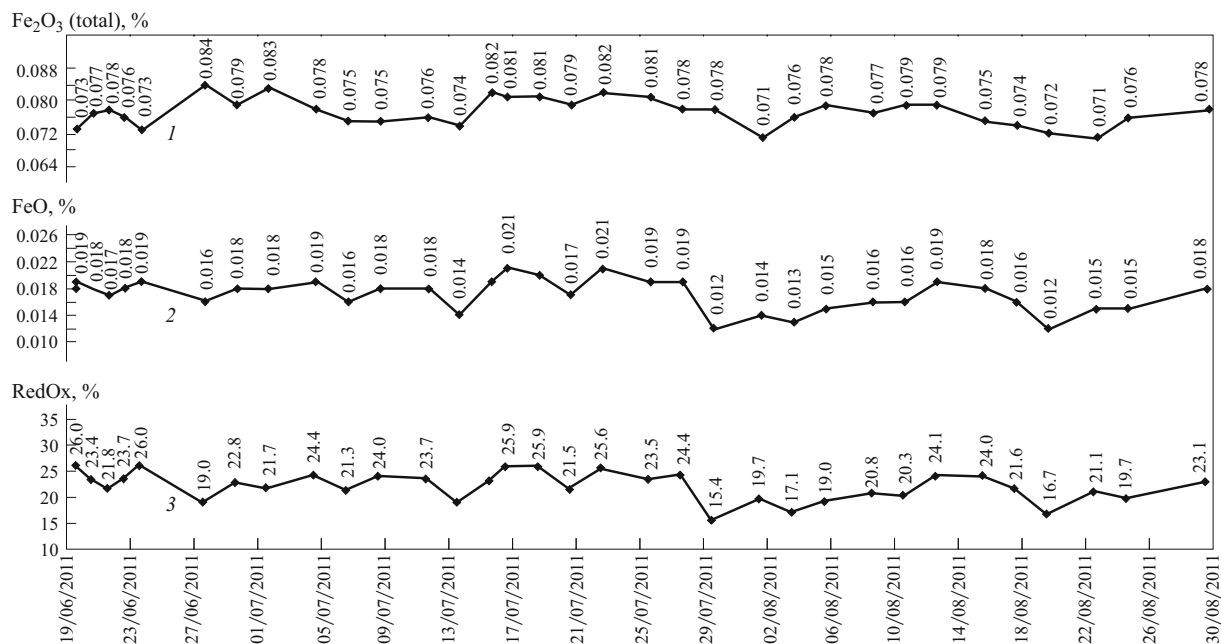
In conventional float-glass manufacture small amounts of sodium sulfate (another compound containing an element with a variable degree of oxidation — sulfur) are added to the batch. The use of sulfate of soda batch with soda/sulfate ratio from 99.5/0.5 to 96/4 is now a generally accepted norm in domestic and world practice in the modern glass industry. Soda /sodium sulfate ratios in the same range are used in glass batch for float-glass manufacture.

In a glass furnace the direct interaction reaction between sodium sulfate and quartz sand proceeds extremely slowly — the rate of this reaction becomes technologically non-negligible only when the temperature reaches of the order of  $1200^\circ\text{C}$ . To accelerate this reaction, as a rule, sodium sulfate is reduced by means of carbon, which is introduced as charcoal into the batch.

It can be stated on the basis of the results of many scientific-technical studies of the basic chemical reactions occur-



**Fig. 3.** Chemical requirement for oxygen in the batch (plant No. 3).



**Fig. 4.** Variation of the RedOx number as a function of the Fe<sup>2+</sup> content in glass (plant No. 3): 1) total iron (Fe<sub>2</sub>O<sub>3</sub> + FeO) in terms of Fe<sub>2</sub>O<sub>3</sub>, %; 2) FeO content, %; 3) RedOx number (FeO/(Fe<sub>2</sub>O<sub>3</sub> + FeO)), %.

ring in sulfate of soda mixtures during making of commercial glass with an aluminum-magnesia calcium-sodium-silicate composition (the type of compositions used in modern sheet-glass manufacture) that the process of melting sulfate of soda batch is characterized by two main steps:

- reduction of sodium sulfate during the batch fusion process and
- interaction of the products of its reduction with quartz sand and other components of the batch and melt.

When sodium sulfate decomposes, sulfur gas and oxygen gas are released. The latter two gases play a very important role when sodium sulfate performs its function as a fining agent.

The use of the indicated quantities of sodium sulfate together with the optimal amount of carbon (to reduce sodium sulfate) in the batch for making float-glass makes it possible to gain all the technological advantages of sulfate of soda glassmaking as compared with, for example, purely soda glassmaking.

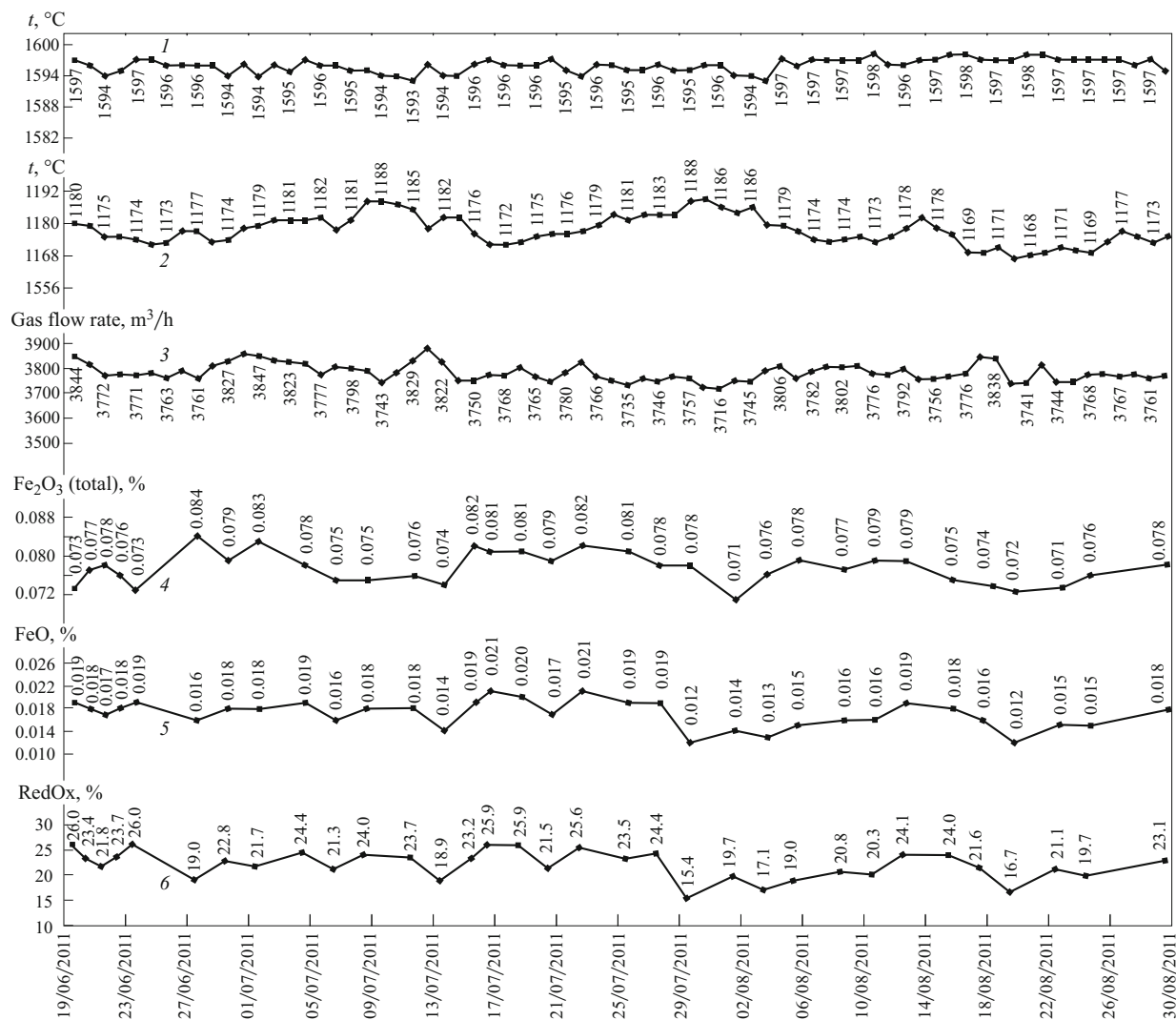
This pertains to, first and foremost, the creation of favorable conditions for preventing technologically inadmissible effects, such as the formation of silica foam (glass foam), which often occurs in purely soda glassmaking. When sodium sulfate is used this is attained as a result of its capability to intensify the dissolution of quartz sand grains in fresh melt. The mechanism of this process consists in the fact that the fused sodium sulfate (melting temperature 884°C), being a surface-active substance, wets the grains of silica, and lowers the activation energy of interaction between the silica and the fresh melt. This intensifies the dissolution of residual silica grains in the melt (the foam is eliminated) with a risk of their accreting into separate sections located on the surface

of the melt. Another important function of sodium sulfate is its role as a high-temperature fining agent. The fining effect, which occurs under the appropriate conditions, consists in emission of the gaseous products from the decomposition of the residual SO<sub>3</sub> (sulfur gas) and oxygen dissolved in the molten glass into the melt.

Entering the cavities of the gaseous inclusions present in the melt volume these gases increase the size of the latter. As a result, their buoyancy force increases in accordance with the well-known Stokes relation, and their rise along the height of the melt and exit from the melt are accelerated.

Correspondingly, the emission of sulfur gas and oxygen, just as the decomposition of the residual SO<sub>3</sub> in the melt, proceed in steps at definite temperatures. The key steps in the emission of SO<sub>2</sub> and O<sub>2</sub> into the melt as a result of the decomposition of the sulfate residue are characterized by the following temperatures. Emission of the gaseous process of decomposition of the sulfate residue through a layer of fused batch occurs at approximately 900°C. The emission of SO<sub>2</sub> and O<sub>2</sub> gases into the melt as a result of the decomposition of the sulfate residue occurs at temperatures ranging from 1050 to 1250°C and at approximately 1350°C, while for oxidized melts emission occurs in the temperature interval 1420 – 1500°C.

Such a temperature range for the emission of the gases SO<sub>2</sub> and O<sub>2</sub> into the melt makes sodium sulfate a high-temperature fining agent. When gases are emitted at high temperature (aside from the above-mentioned process whereby the volume of the gaseous inclusions already present in the melt increases with their buoyancy force increasing and the emission from the melt accelerating) large bubbles are formed. Gases supersaturating the molten glass can be re-

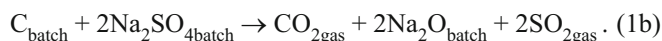
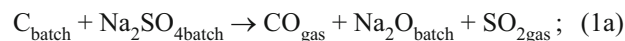


**Fig. 5.** Temperatures of the gas space and molten glass versus the iron oxide content in the glass (plant No. 3): 1) maximum temperature of the gas space,  $^\circ\text{C}$ ; 2) bottom temperature,  $^\circ\text{C}$ ; 3) gas flow rate,  $\text{m}^3/\text{h}$ ; 4) total iron content ( $\text{Fe}_2\text{O}_3 + \text{FeO}$ ) in terms of  $\text{Fe}_2\text{O}_3$ , %; 5) FeO content, %; 6) RedOx number, %.

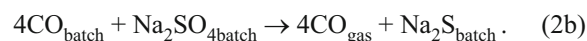
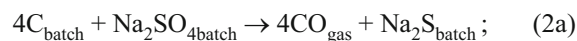
leased in these bubbles, also promoting more complete fining of the melt. A non-negligible, technologically favorable factor promoting more intense growth of gaseous inclusions with intensification of the melt fining process is the occurrence of high-temperature melt fining effects at correspondingly lower (because of the high temperature) melt viscosity. In addition, by the time temperatures above  $1250^\circ\text{C}$  are reached in the glassmaking process practically no component of the melt (for the float-glass composition considered here) has the slightest technologically non-negligible capability of releasing gas.

The high effectiveness of sodium sulfate as a fining agent is convincingly proved by the fact that throughout virtually the entire history of the use of the float-method of producing sheet glass this compound has been used as the only fining addition to batch used to make this glass.

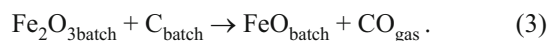
Carbon can react directly with oxidizers in the batch, i.e., with sodium sulfate or  $\text{Fe}_2\text{O}_3$  ( $\text{Fe}^{3+}$ ), according to the following reactions:



Sodium sulfide can form at very high carbon content:



Carbon can reduce a portion of  $\text{Fe}_2\text{O}_3$  to FeO via the reaction





The reactions (1) – (3) are solid-state reactions, and the entire conversion is limited because the contacts between carbon and sodium sulfate or iron oxides are limited.

A large portion of the  $\text{CO}_2$  emission occurs from carbonates, which during heating of the batch and melt react in the batch with carbon particles:



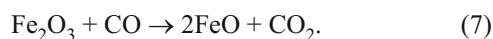
The reaction occurs at temperature 500 – 900°C. In the batch CO gas can react with sulfates:



Other reactions can also occur:

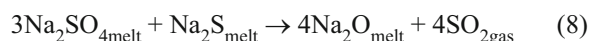


Carbon monoxide can also lower the valence of the  $\text{Fe}^{3+}$  ions via the reaction

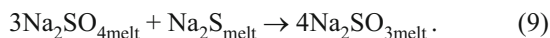


Carbon monoxide release manifests in parallel to  $\text{CO}_2$  release but at a lower emission temperature in the range 650 – 1000°C.  $\text{SO}_2$  emission starts at approximate temperature 850 – 900°C and continues after the batch melts. The peak emission of  $\text{SO}_2$  occurring at approximately 900°C can be attributed to the reaction (1a) or (5).

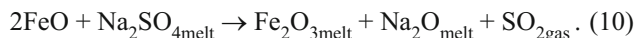
Melt with residual sulfate and sulfide at 1050 – 1250°C reacts as follows:



or



Another reaction with  $\text{Na}_2\text{SO}_4$  participation, which can occur in the presence of iron oxide in the melt, occurs according to the equation



According to the data of [4], this reaction occurs at temperature 1300 – 1350°C.

The general gas-emission equation depends on the addition of sodium sulfate and carbon to the melt, the maximum glassmaking temperature, and the redox state of the melt.  $\text{SO}_2$  and  $\text{O}_2$  gas bubbles form at temperatures above 1450°C.

For batch with high carbon content a large portion of sodium sulfate reacts at temperatures below 1200°C. But here fining requires more time than at temperatures above 1400°C.

As the water content in batch increases, the fining onset temperature decreases and gas release during primary fining can increase considerably [4].

The example presented above of the main chemical reactions occurring in a molten-glass batch (melt) during the production of sheet glass shows the importance of correctly organizing and creating the proper conditions for these processes.

On this basis there follows the natural conclusion that the addition of sodium sulfate and carbon to batch for making float-glass in application to the overwhelming majority of commercial glasses must be balanced with one another in a definite manner. According to practical commercial data, the value of one item in this balance (the content of sodium sulfate in the batch for which under the conditions for making float-glass the advantages of sulfate of soda glassmaking are quite fully realized) falls within the limits  $2.5 \pm 0.2\%$  (for the sulfate of soda ratio), permitting sodium oxide to be introduced into float-glass via sodium sulfate in an amount equal to 2.5% of its total content.

The carbon content in batch for decomposition of sodium sulfate (in terms of carbon), as formulated back in the 1930s by H. Jebsen-Marwedel and long-standing classic recommendations, should be 6 – 7% (this is approximately 1.5 times greater than the theoretical amount of carbon, as determined by the stoichiometric relations following from the equation governing the reduction of sodium sulfate by carbon). This is especially important at a time in the development of the glass industry when up to 15% of the total content of sodium oxide in the glass was introduced via sodium sulfate.

The subsequent advancement of the sheet-glass industry and, of course, the transition to production by the float-glass method led to the adjustment of the volumes of carbon introduced into the batch as a reducing agent.

In the first place, sodium sulfate gradually fell out of use as one of the main raw materials for introducing sodium oxide into glass and is no longer used. In addition, at present sodium sulfate for introducing sodium oxide into glass at the level of the soda to sodium sulfate ratios from 99.5/0.5 to 95/5 is used in a number of cases generally without using carbon as a reducing agent. Accelerating the interaction of sodium sulfate with the melt made possible wide adoption of high-temperature glassmaking in industry. In float-glass manufacture, sodium sulfate and carbon became necessary components of the batch for glassmaking, largely determining the effectiveness of the glassmaking processes and product quality. It must be emphasized that in the presence of iron oxides in glass sodium sulfate and carbon play decisive roles as oxidizing and reducing agents, respectively, in securing the required conditions for obtaining batch with the required ORP for normal flow of redox processes in molten glass and the possibility of controlling these properties as well as the diathermancy of the melt.

To make the transition to the analysis and determination of rational approaches to using sodium sulfate and carbon in float-glass manufacture one must start from that fact that it is technologically wrong, in our opinion, to mechanically trans-

fer technologically successful solutions for this problem from one conventional system for manufacturing float-glass to a different conventional system (even if these systems are structurally similar). The reason is that from a host of technological standpoints glassmaking furnaces in operating systems for manufacture of float-glass operate in different regimes and under different technological conditions. Each float-glass system (and, therefore, the corresponding glass-making furnace) works on a glass composition and particular component (with respect to the initial materials) batch composition which are specific to each system, using materials with a definite particle-size distribution. The quality of the glass batch obtained meets definite requirements for a given system. In addition, glassmaking is done in a furnace with individual structural features with definite heat load distributions over the length of the melting tank with temperature fields in the melt volume which are characteristic only to a particular furnace.

A question of primary importance for developing a technology for making sulfate of soda float-glass is the optimal (for maximum use of the advantages of this form of glassmaking) amount of sodium sulfate and charcoal (carbon) introduced into the batch in order to reduce it.

An inadequate amount of sodium sulfate in the batch results in the formation of silica striae, drops, and massive inclusions on the glass strip as well as disruptions of the fining of the molten glass. Excess sodium sulfate in the batch gives rise to stable, dense and in some cases extended foam in the melting zone, which can cause small islands of foam to enter (if the foam detaches from the main mass) right up to pinching of the furnace and seriously affect glass quality. In addition, the foam screens the molten glass lying beneath it from the heat flowing from the flame space.

As result, heat transfer to the molten glass can decrease, which in turn will cause a deficit of heat required to fine the molten glass with all the negative consequences following from this.

As far as charcoal is concerned, if it is present in the optimal amount in the float-glass batch, aside from the reduction of sodium sulfate, a low-temperature melt of a mixture of  $\text{Na}_2\text{SO}_4$  with one of the products of decomposition of sodium sulfate — sodium sulfide — forms. This results in the appearance of a liquid phase at earlier stages of glassmaking and thereby activates the glass formation processes. The use of charcoal decreases the coverage of the melting area by glass foam. This has a very favorable effect on the glass-making process as a whole. A drawback is that charcoal in the batch creates excess foam. As a result, fining does not proceed satisfactorily and the number of inclusions of the type silica foam in the glass increases. Excess charcoal results in an elevated level of silica inclusion in the glass strip.

The opinion that the range of numerical values for the soda/sulfate ratio in the batch that characterize the sodium sulfate content is quite narrow is illegitimate. Under industrial conditions a 0.1% increase or decrease of the fractional

**TABLE 1.** Comparison of the Technical Indicators of Technical-Grade Sodium Sulfate

Indicator	Technical grade sodium sulfate GOST 6318–77, grade A, sort 1	Technical grade sodium sulfate TU 2141-114-05766575–2004
	Supplier	
	Karpov Chemical Plant, JSC (Mendeleevsk, Tatarstan)	Gasprom Neftekhim Salavat, JSC (Salavat, Bashkortostan)
Sodium sulfate $\text{Na}_2\text{SO}_4$ content, wt.%, not less than	98.0	95.0
Water insoluble residue content, wt.%, not more than	0.9	0.4
NaCl content, wt.%, not more than	0.7	1.2
$\text{CaSO}_4$ content, wt.%, not more than	0.1	1.0
Magnesium ion content, wt.%, not more than	0.1	0.1
Iron oxide content, wt.%, not less than	0.015	0.03
Water content, wt.%, not more than	1.0	1.0
Particle size distribution	Certificate of Quality	Analysis bulletin
particle content, wt.%, with size, mm:		
> 2.0	None	0.81
0.5 – 2.0	99.21	4.12
0.1 – 0.5	0.76	65.86
< 0.1	None	29.19

content of sodium sulfate in batch produces noticeable technological disturbances in the organization of the glassmaking process.

The correct organization of the redox processes occurring in melt and the solution of the problems of regulating (controlling) them depends on many factors.

The special significance of increasing the quality of the sand used in glassmaking has been noted above with respect to the iron content, particle size distribution, and limited number of suppliers. However, the role of sodium sulfate and charcoal in batch determines the flow of redox processes during glassmaking.

Sulfate is an oxidizer, which effectively fines molten glass and accelerates glassmaking. On the other hand, carbon is a reducing agent for glassmaking.

The effect of sodium sulfate from different suppliers on the glassmaking efficiency was investigated for two operating float-lines (Table 1).

It was found that aside from the content of the main substance the determining aspect is the size distribution of so-

**TABLE 2.** Comparison of the Technical Properties of Granulated Charcoal and Carbon-Containing Material (CCM)

Property	Granulated charcoal TU 12.36.210–91		CCM TU 1971-002-80759242–2008	
Ash content, %	No more than 10.5		No more than 5.0	
Volatile substances emission, %	30 – 45		No more than 5.0	
Total sulfur content, wt. %	No more than 1.0		No more than 1.0	
Total moisture content, wt. %	No more than 5.0		3.0 – 8.0	
Carbon content, wt. %	65 – 70		No less than 91.0	
Particle-size distribution, content, wt. %, particles of size, mm:	TU 12.36.210–91	Certificate of Quality	TU 1971-002-80759242–2008	Analysis bulletin
0.63 – 1.0	No more than 3.0	2.8	Content of 0.1 – 3.0 mm particles, provided (100%)	0
0.20 – 0.63	55 – 80	43.9		69.3
0.1 – 0.2	No more than 25	18.4		23.3
< 0.1	No more than 15	14.6		7.4

dium sulfate particles, especially the content of dust-size fractions in it.

The use of sodium sulfate with the optimal particle-size distribution made possible the following:

- considerable improvement of batch mixing in mixers and batch behavior in the feeding hoppers of the combined shop (now hanging of materials during hopper unloading);
- improvement of batch melting (sharper batch – foam boundaries);
- increase of the molten glass temperature beneath the batch and decrease of the maximum temperature in furnace with constant gas flow rate.

Sodium sulfate as a fining agent is introduced into batch simultaneously with reducing charcoal. The charcoal plays an important role in the redox processes. The properties of charcoal as a reducing agent largely depend on the type and quality of the charcoal and its content of the main substance — carbon. Theoretically, 4.22% carbon (with respect to sulfate) is required to reduce sodium sulfate. In practice, approximately 1.5 times more carbon is introduced into batch [5].

We have studied charcoal obtained from different producers. Its technical properties are presented in Table 2.

The operational indicators of the furnace improved substantially on switching to CCM type carbon. The boundaries of the glass foam shrunk; the bottom temperatures of the molten glass below the batch increased by 5 – 10°C; and, the maximum temperature along the furnace roof decreased by 4 – 5°C. The advantages of CCM type coal are, first and foremost, a better optimal particle-size composition. The 0.1 – 0.315 mm fraction is 87%; the content of the main substance — carbon — is higher than 90%.

A comparative assessment undertaken by us of the content of sodium sulfate and carbon in batch used for float-glass manufacture and used at the plant — the object of the investigation (plant No. 3) — showed a higher content of both components in this batch than at plants Nos. 1 and 2 (Table 3).

The sodium sulfate and carbon contents calculated for the batch recipes from plants Nos. 1 and 2 showed that the highest amount of sodium sulfate and carbon is introduced into the batch used at plant No. 3, which is the object of study. The plant closest to No. 3 with respect to the batch parameters studied, the capacity of the glassmaking furnace, the construction of the furnace, and the technological operating conditions is plant No. 2 with satisfactory quality indicators of the finished product with respect to bubbles and inclusions. On this basis the batch parameters (according to the content of sodium sulfate and carbon) for this plant were taken as the base parameters. The transfer to the base operational indicators of the float-system in plant No. 3 (object of study) will be accomplished in several steps so as to decrease the sodium sulfate/carbon ratio from 3.84 to 2.99% (Table 4) with this parameter changing in steps 0.1 – 0.15%; the operation is to be completed in 10 – 15 days. The carbon content in the batch (with respect to the sodium sulfate content) will be decreased from 7.6 to 4.7%, i.e., by 2.9%, likewise in several steps with this parameter changing in steps 0.12%.

As a result of the restructuring of the redox state of the batch (accomplished by changing the content of sodium sulfate and carbon in the batch) the RedOx number of the batch will change. Our calculations show that it will increase by

**TABLE 3.** Batch Mixtures for Float-Glass from Different Glass-making Plants

Component	Component content in batch, kg, per 1000 kg glass		
	Plant No. 1	Plant No. 2	Plant No. 3
Sand	718.98	706.00	712.10
Soda	211.50	218.80	209.50
Chalk	68.44	62.40	50.40
Dolomite	170.40	174.90	181.00
Feldspar	30.02	36.20	41.00
Sulfate	8.54	6.80	10.80
Carbon	0.62	0.43	1.27



**TABLE 4.** Computational Results for the  $\text{Na}_2\text{O}$  Amount Introduced into Glass via Sodium Sulfate and Soda

Plant	$\text{Na}_2\text{O}$ introduction into glass via sulfate, % of total $\text{Na}_2\text{O}$ amount	$\text{Na}_2\text{O}$ introduction into glass via soda, % of total $\text{Na}_2\text{O}$ amount	Ratio of sulfate-introduced $\text{Na}_2\text{O}$ to soda-introduced $\text{Na}_2\text{O}$
No. 1	0.30	12.80	2.34/97.66
No. 2	0.26	13.48	1.92/98.08
No. 3	0.37	12.37	2.99/97.01

+1.10 (to +5.17%). It is known that a positive value of the RedOx number of the batch corresponds to white glass made from this batch. An increase of the RedOx number of the batch occurring in the present case (from +1.10 to +5.17%) means that the measures taken will result in a more stable redox state corresponding to white glass. The values of the RedOx number of glass in the case at hand correspond to 19 – 24%. These RedOx numbers correspond to optimal values for the production of float-glass, equal to 24 – 25%. This is a necessary condition for securing high float-glass quality with respect to bubble and inclusion defects.

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